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Surface wave propagation at semiconductor dielectric interface in presence of a radial density gradient

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A dispersion relation governing the surface wave propagation in the composite structure of a cylindrical semiconductor coated with thin layer of dielectric material is derived and studied for different values of inhomogeneity parameter and dielectric thickness parameter. A linear density grading is assumed in the semiconductor along the radial direction.

1. Introduction

Robinson and Vural (1968) reported the two stream interaction in a thin semiconductor layer with the aid of quasistatic approximation and derived the dispersion relation for slow waves in semiconductor plasmas. Further Robinson (1970) proposed electron hole plasma instabilities in a semiconductor and discussed wave propagation for a thin plasma slab in the presence of a low magnetic field, and also discussed surface wave propagation on a thick semiconductor plasma slab surrounded by a dielectric medium. Baraff & Buchsbaum (1965, 1966, 1966), Mizushima & Sudo (1970), Baynham *et al* (1973) and Tiwari & Verma (1976), reported surface wave propagation on the composite structures of semiconductor plasma slabs, with and without external magnetic field. In an earlier communication Tiwari and Verma 1975 reported surface wave propagation on the composite structure of an inhomogeneous semiconductor plasma column coated with a thick layer of dielectric material.

The purpose of this paper is to discuss surface wave propagation on a composite structure of a semiconductor plasma column coated with a layer of thin dielectric material, in the presence of a density gradient along the radial direction. The dispersion relation is studied for both axial and dipolar modes.

2. Analysis

The permittivities of different media in case of semiconductor plasma column coated with thin layer of dielectric material can be written as

$$\begin{aligned}
\epsilon(r) &= \epsilon_0\left\{1-\frac{\omega_p{}^2}{\omega^2}\left(1-\frac{\alpha r}{a}\right)\right\} && 0<r<a \quad \text{(semiconductor plasma)} \\
\epsilon(r) &= \epsilon_0\epsilon_d && a<r<b \quad \text{(dielectric medium)} \qquad \ldots (1)\\
\epsilon(r) &= \epsilon_0 && r>b \quad \text{(free space)}
\end{aligned}$$

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where ϵ_d is the dielectric constant of the coated material and α is the inhomogenety parameter. The analysis is carried out under quasistatic approximation and the wave propagation is assumed along z-direction. If we assume a travelling wave solution for the potential of the form :

$$\phi = R(r) \exp\left(-j\left(n\theta+\beta E\right)\right)$$

where $R(r)$ is the radial component of the scalar potential and β is the propagation constant. From the boundary condition, the scalar potential and its derivaive should be continuous at the boundaries of the different media. Following the process as outlined by Tiwari & Verma (1975), we get dispersion relation for the axial mode (i.e. $n = 0$) as follows

$$K^2[\beta^2a^2(4AC-4B^2)+16\beta^2a^2AB]+K[\beta^4a^4(2B-2C-0\ 66A)] \\ +\beta^2a^2[4f(A+4B+C+2.165)+(6.08-8B)]-4f = 0 \qquad \dots (2)$$

where $K = \dfrac{\omega_p{}^2}{\omega^2}$; $A = (7-6\alpha)/12$; $\quad B = (5-4\alpha)/20$
$C = (3-2\alpha)/6$

and $\quad \delta = \dfrac{b-a}{a} < 1$

$$f = \epsilon_d\beta a - \frac{-K_1(\beta a)\left\{\dfrac{1}{\beta a}+\delta^2\dfrac{\beta a}{2}\right\} - \epsilon_d K_0(\beta b).\delta}{-K_1(\beta b)\delta-\dfrac{\epsilon_d}{\beta a}\left\{1-\delta+\delta^2\left(1-\dfrac{\beta^2a^2}{2}\right)\right\}}$$

where a is the radius of the column and b is the outer radius of the semiconductor dielectric structure. Similarly for dipolar mode, the dispersion relation can be put as

$$K^2[(\beta^2a^2A_1+n^2E_1)(B_1+\beta^2a^2C_1+n^2D_1)-(\beta^2a^2D_1+A_1(n^2+1))^2]$$

$$+K\left[\left(n^2-f-\frac{\beta^2a^2}{3}\right)\left(C_1\frac{\beta^2a^2}{2}+B_1+D_1n^2\right)+(A_1\beta^2a^2+n^2E_1)\right.$$

$$\left.\left(1.2+f+\frac{\beta^2a^2}{7}-\frac{n^2}{5}\right)\right]$$

$$+2[0.2(\beta^2a^2+n^2+1)-f)(A_1(n^2+1+\beta^2a^2D_1)]\left[n^2+\frac{\beta^2a^2}{3}-f\right]\left[1.2+\frac{n^2}{5}-f\right]$$

$$-\left[.33+\frac{\beta^2a^2}{5}+\frac{n^2}{3}-f\right] \quad = 0 \qquad \dots (3)$$

where $\quad A_1 = (3\alpha-4)/12$; $\quad B_1 = (5\alpha-6)/6$
$C_1 = (7\alpha-8)/56$; $\quad D_1 = (5\alpha-6)/30$
$E_1 = (\alpha-2)/2$

3. Results and Discussion

The dispersion relations have been solved with the help of an IBM-1130 computer and plotted for various values of inhomogeneity parameter α and δ. The dispersion relations are also plotted for a homogeneous carrier density plasma. and are shown by dashed lines in figures.

3.1. *For axial mode*

Eq. (2) presents the dispersion relation for the axial mode, which is quadratic in form and hence has two real roots; these two roots are sketched in figures 1

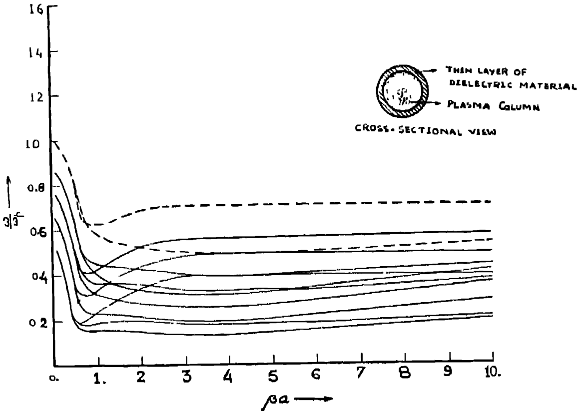

Fig. 1. Dispersion curves for axially symmetric surface wave mode for different values of α and δ.
A. $\alpha = 0$, $\delta = 0$, B. $\alpha = 0.0$, $\delta = 0.078$, C. $\alpha = .3$, $\delta = .078$, D. $\alpha = .3$, $\delta = .158$, E. $\alpha = .5$, $\delta = 0$, F. $\alpha = .5$, $\delta = .078$, G. $\alpha = .5$, $\delta = .158$, H. $\alpha = .7$, $\delta = 0$, I. $\alpha = .7$, $\delta = .158$, J. $\alpha = .9$, $\delta = 0$, K. $\alpha = .9$, $\delta = .078$, L. $\alpha = .9$, $\delta = .158$.

and 2. Figure 1 clearly shows the surface wave mode because the condition $\epsilon_p<1$ (where ϵ_p is the relative dielectric constant of the plasma), which is the essential condition for surface waves to exists (Oliner & Tamir 1962) at semiconductor-dielectric interface, is satisfied. The surface wave mode is affected slightly by the variation of α and δ. The coating thickness parameter affects the propagation to some extent For smaller values of δ such as $\delta = .078$ the fields do not remain bound in the semiconductor dielectric interface but they diffuse to the dielectric air interface. Observation of phase and group velocity of these waves confirm the propagation of forward waves at the interface.

Figure 2 shows the propagation of electromagnetic waves through the plasma. Here as one can see from the fig. 2 the phase velocity is greater than the velocity of light. This type of propagation is referred to as fast wave propagation or a pass band situation (Pinder and Foulds 1966). The plot is not much affected by variation in α but is severely affected by δ values, condition $\delta = 0$ corresponds to

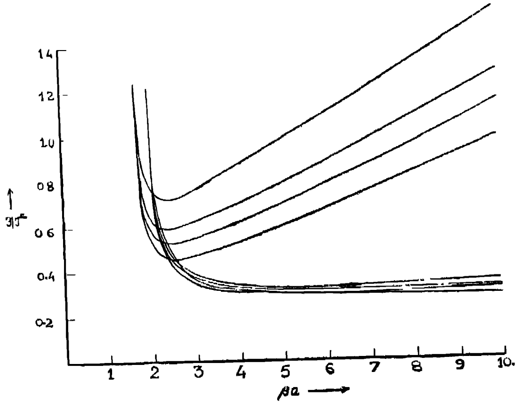

Fig. 2. Effects of α and δ on the propagation of waves in plasma.
A. $\alpha = 0$, $\delta = 0$, B $\alpha = 0$, $\delta = .078$, C. $\alpha = 3$, $\delta = .158$, D. $\alpha = 5$, $\delta = 0$, E. $\alpha = .7$, $\delta = 0$, F. $\alpha = 7$, $\delta = 078$, G. $\alpha = .9$, $\delta = 0$, H. $\alpha = .9$ $\delta = .078$

the situation where free space surrounds the plasma column and we observe fast wave propagation because there is no trapping of fields at the interface, whereas for finite values of δ, part of the field is present at the surface indicating suppression

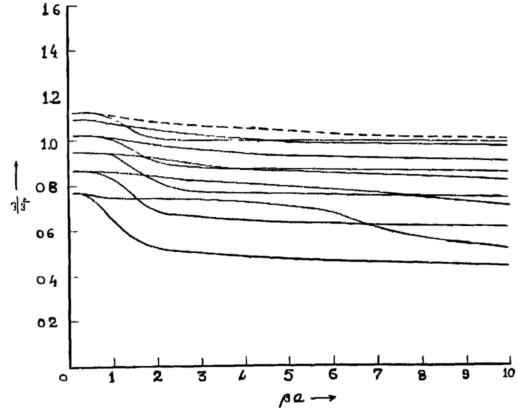

Fig 3. Dispersion curves for dipolar surface wave mode for different values of α and δ:
A. $\alpha = 0$, $\delta = 0$, B $\alpha = 0$, $\delta = .078$, C. $\alpha = .1$, $\delta = .078$, D. $\alpha = .3$, $\delta = .078$, E $\alpha = .3$, $\delta = 0$, F. $\alpha = .5$, $\delta = .078$, G. $\alpha = .5$, $\delta = 0$, H. $\alpha = .7$, $\delta = .158$, I. $\alpha = .7$, $\delta = 0$, J. $\alpha = .9$, $\delta = .158$, K. $\alpha = .9$, $\delta = 0$.

of the wave. Moreover at this particular instant the wave propagates with constant phase velocity in the whole range of normalised propagation constant.

3.2 *For dipolar mode*

Eq. (3) presents the dispersion relation for the dipolar mode. Figure 3 clearly shows the surface wave mode. This mode is not much affected by the variation in α and δ and propagates in the whole range of normalised propagation constant.

Figure 4 shows the propagation of *em* waves in plasmas. This mode is not much affected by the variations in α and δ and propagates with constant phase

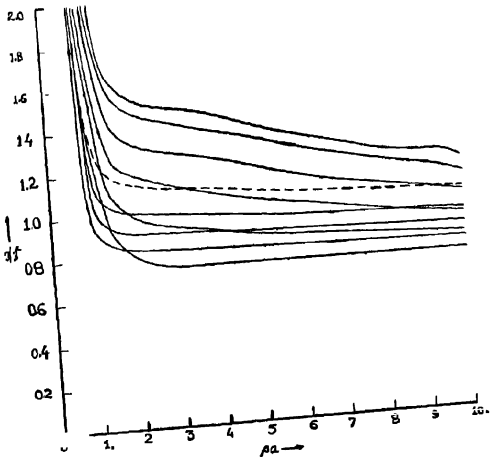

Fig. 4. Effects of α and δ on the wave propagation for dipolar mode : A. $\alpha = 0$, $\delta = .078$, B. $\alpha = .1$, $\delta = .078$, C. $\alpha = .3$, $\delta = 0$, D. $\alpha = .3$, $\delta = .158$, E. $\alpha = .3$, $\delta = .078$, F. $\alpha = .5$, $\delta = .078$, G. $\alpha = .5$, $\delta = 0$, H. $\alpha = .7$, $\delta = .158$, I. $\alpha = .7$, $\delta = 0$, J. $\alpha = .9$, $\delta = .078$.

velocity less than that of light ($\beta^2 > \omega^2/c^2$) for the whole range of normalised propagation constant.

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